



**Urban-Small Building Complex Environment:  
Comparing Stable Patterns from Two Similar  
Urban Field Studies, Volume AS-1**

**by Gail Vaucher**

**ARL-TR-4256**

**September 2007**

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White Sands Missile Range, NM 88002-5501

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**ARL-TR-4256****September 2007**

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## **Urban-Small Building Complex Environment: Comparing Stable Patterns from Two Similar Urban Field Studies, Volume AS-1**

**Gail Vaucher**

*Computational and Information Sciences Directorate*

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<b>14. ABSTRACT</b> The urban stability cycles are not clearly defined. This technical report investigates the urban stability cycle through the use of statistical and empirical observations. These observations are gleaned from two independent urban data sets acquired around a common building complex. The text includes the general features of the test site and a description of the two data sets: <i>WSMR 2003 Urban Study (W03US)</i> and <i>WSMR 2005 Urban Study (W05US)</i> . Earlier research found both rural and urban-city stability cycles in the <i>W03US</i> data, which led to a characterization of stable conditions from the <i>W05US</i> data. The <i>W05US</i> stable patterns are the baseline for the <i>W03US</i> and <i>W05US</i> stable pattern spatial and temporal comparisons reported in this document. An executable Test Plan concludes the text and represents the next step toward characterizing the urban stability patterns and defining the diurnal urban-stability cycles.					
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## Executive Summary

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Civilian and Soldier performance in an urban environment can be improved with an understanding of the urban diurnal stability cycles. The assessment of environmental impacts, such as pollution dispersion from traffic and other near surface sources, is a function of stability. Stability conditions can keep pollutants trapped near the surface or dispersed aloft. A contemporary civilian application demonstrating the serious nature of environmental impact was presented in a recent news article concerning the successful execution of the 2008 Olympic Games in Beijing, China, a city known for its pollution and subsequent health problems (1). A Soldier's performance in an urban environment is just as much of a concern to our nation; thus, urban stability patterns are actively being researched by the U.S. Army Research Laboratory.

The atmospheric boundary layer (ABL) has a diurnal cycle of radiative heating and cooling caused by a daily cycle of sensible and latent heat fluxes. The fluxes are generally confined to a shallow layer near the ground. Static stability controls the ABL formulation and has three subcategories that can be used to characterize the surface radiation: unstable, neutral, and stable. These categories are based on a comparison between an air parcel to its surrounding environment at the same pressure or height. In a rural environment, these three conditions follow a cycle of nighttime-stable, daytime-unstable, and two transitions-neutral to link the day and night atmospheric stability conditions.

For the urban atmosphere, the stability cycle is not as clearly defined. While one may intuitively associate an unstable and neutral atmosphere with the urban environment, research shows that there are mechanisms for manifesting urban-stable conditions, some of which include diurnal radiative cooling (diurnal cycles), advection (i.e., fronts), and local forcing (i.e., evaporation).

In this technical report, we investigate the definition of an urban stability cycle through the use of statistical and empirical observations. These observations are gleaned from two independent urban study data sets acquired over a common single-subject-building test site. Over the course of this text, the general features of the urban test site are introduced, followed by a description of the two data sets entitled, *White Sands Missile Range (WSMR) 2003 Urban Study (W03US)* and *WSMR 2005 Urban Study (W05US)*. Since earlier research found both rural and urban-city stability cycles in the *W03US* data set, the subsequent *W05US* data analysis fine-tuned the research by focusing on just the stable conditions found in the urban–small complexes environment. The resulting *W05US* stable patterns are presented as the baseline for this investigation's data comparisons. A reanalyzed *W03US* data set challenges the precision of this baseline by focusing on just the *W03US* stable conditions, emphasizing the general patterns of occurrence. Both the *W03US* and *W05US* stable patterns are compared with respect to spatial and temporal dimensions.

The strongest spatial and temporal attributes observed from both stable data resources were the following:

1. The open environment east of the building showed the greatest occurrence of stable conditions, while the secondary preference was unclear. The secondary preference was presumed to be a function of local forcing factors involving the airflow and anthropological patterns.
2. The diurnal cycle for the *W03US* and *W05US* stable environments showed a strong preference for the Night Period first, followed by the Sunrise Transition. The *W05US* data set reported the Sunset Transition as a third preferred period for stable conditions, but the shorter data set from *W03US* did not concur.

The climatologically strong March winds integrated into the two NM data sets may be skewing the stability pattern results. Also, both data sets were acquired during the equinox time period, to minimize diurnal heating/cooling effects. Therefore, this author recommends 1) that a measurement series be conducted under less windy conditions, to balance the radiative cooling effects, and 2) that the non-equal diurnal solar cycles or solstice environments be explored. The NM June solstice time period coincides with a “low-to-no” wind cycle. Thus, the NM summer solstice time period would favor radiative cooling and potentially provide a significant contribution to the urban stability investigation. An example of a summer solstice field study Test Plan and Test Site Design concludes the report. These documents represent the next step toward characterizing the urban stability pattern and defining the diurnal urban-stability cycles.

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## 1. Background

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Understanding the urban diurnal atmospheric stability patterns and mechanisms are crucial to both civilian and military applications. Health, tools, and strategic planning are just three areas that can be improved by knowing and exploiting repeatable stability patterns. The assessment of environmental impacts, such as the pollution dispersion from traffic and other near surface sources, is a function of stability and strongly influences both military and civilian performance in that environment. A recent civilian example of environmental impact applications was given by the news media as they described concern over the successful execution of the 2008 Olympic Games in Beijing, a Chinese city known for its pollution (*1*). The U.S. Army Soldier's performance in an urban environment is no less of a concern; thus, urban stability patterns are actively being researched by the U.S. Army Research Laboratory.

The atmospheric boundary layer (ABL) has a diurnal cycle of radiative heating and cooling caused by a daily cycle of sensible and latent heat fluxes. The fluxes are generally confined to a shallow layer near the ground. Static stability controls the ABL formulation and has three subcategories that can be used to characterize the surface radiation. These categories are based on a comparison between an air parcel to its surrounding environment at the same pressure or height. When the air parcel is warmer, the parcel is positively buoyant and rises (unstable stability conditions). When cooler, it is negatively buoyant and sinks (stable stability conditions). When the parcel is the same temperature as its surroundings, there is a zero buoyant force (neutral stability conditions). In a rural environment, these three conditions follow in a cycle of nighttime-stable atmosphere, near sunrise-neutral atmosphere, daytime-unstable atmosphere, near sunset-neutral atmosphere, and back to nighttime-stable atmosphere.

For the urban atmosphere, the stability cycle is not as clearly defined. While one may intuitively associate an unstable and neutral atmosphere with the urban environment, research shows that there are mechanisms for manifesting urban-stable conditions. Some of the mechanisms include diurnal radiative cooling (diurnal cycles), advection (i.e., fronts), and local forcing (i.e., evaporation).

In this technical report, we investigate the definition of an urban stability cycle through the use of statistical and empirical observations. These observations are gleaned from two independent urban study data sets acquired over a common single-subject-building test site. In chapter 2, the general features of the urban test site are given. Chapter 3 describes the two data sets, which are entitled *White Sands Missile Range (WSMR) 2003 Urban Study (W03US)* and *WSMR 2005 Urban Study (W05US)*. Since earlier research projects found both rural and urban-city stability cycles in the *W03US* data set, a subsequent *W05US* data analysis fine-tuned the research by focusing on just the stable conditions found in the urban-small complexes environment. The resulting *W05US* stable patterns are presented in chapter 4 as the baseline for this investigation's

data comparisons. A reanalyzed *W03US* data set challenges the precision of this baseline by focusing on just the *W03US* stable conditions, emphasizing the general patterns of occurrence. In chapter 5, both the *W03US* and *W05US* stable patterns are compared with respect to spatial and temporal dimensions. The conclusions section congeals the repeated stability patterns. Supplementing the text are three appendices that document the general stable characterization patterns from each data set and presents an executable Test Plan, which represents the next step toward clarifying the diurnal urban-stability cycles.

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## 2. Urban-Small Complexes Environment

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The environment selected for this urban stability investigation consisted of a small complex of office buildings at WSMR, NM (see figure 1). The subject building was a two-story, concrete-blocked, rectangular, nearly flat-roofed structure. A single story “dog house” was perched on the south side of the roof. To the north of this subject building was a similarly constructed building of equal height; to the south was a single-story building; to the west was a staircased, 1- to 2-level building; and to the immediate east was a small plot of green tailored grass, followed by a sidewalk and a paved four-row parking lot. During the *W03US* data acquisition period, automobiles were confined to the farthest two parking lot rows and no vehicle traffic was permitted near the towers. In 2005, the test site layout included the farthest two parking lot rows. Thus, no automobiles were permitted access to this area during the *W05US* data acquisition. Two, two-story tall trees covered the northeast and southeast corners of the compass-aligned subject building. Bushes framed the front door area. Nearly level gravel and dirt surfaces were between buildings.



Figure 1. *W03US* building and tower placement. The *W05US* test site used this foundational configuration and added three tripods.

The weather pattern during both *W03US* and *W05US* acquisition periods ranged from calm clear skies to typical NM spring windstorms (winds sustained at greater than 10 m/s) due to tight pressure gradients aloft. The month of March (solar equinox) was selected for both data acquisition periods in order to minimize the systematic effects of the diurnal heating/cooling cycle.

### 3. Data Resources

During the *W03US* (2003 March), data were acquired from four 10-m towers on each side of the subject building. A shorter 5-m tower was installed on the roof. Coincident with this stability research was an airflow study around the single urban building structure. Exact tower placement was based on optimizing stability and airflow pattern extraction. Figure 2 shows the tower positions relative to the subject building. Tower orientation with respect to the building was skewed to accommodate prevailing wind direction.

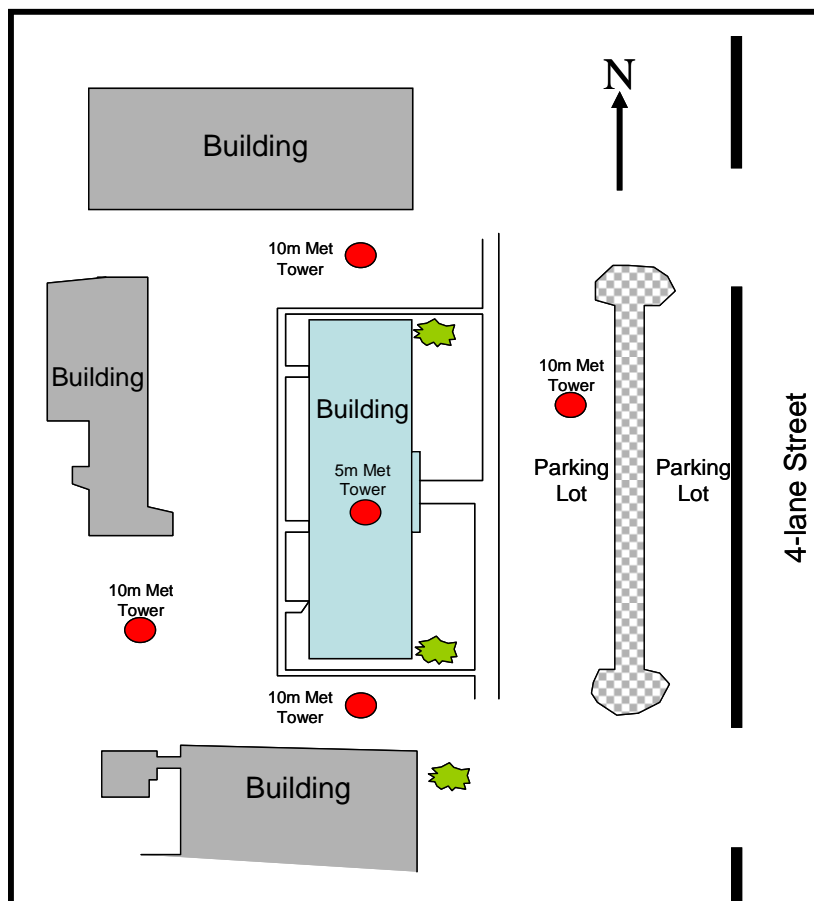


Figure 2. Test site top-down view for the *W03US*.

NOTE: Gray areas represent buildings, with the subject building as blue. Green jagged circles are trees. Red filled circles represent the towers.

NOTE: Each 10-m tower reference is labeled and referred to by its compass position relative to the single subject building. For example, the North tower is the 10-m tower placed on the north side of the subject building. The South tower is the tower placed on the south side of the building.

With the primary field study objectives being to qualitatively characterize mean surface layer stability transition and airflow patterns, the sensors selected included a barometer (Vaisala PTB-101B), thermometer (Campbell-T107), thermometer/hygrometer (Vaisala-HMP45AC), anemometer (RM Young Wind Monitor-05103), and pyranometer (Kipp/Zonen-CM3). A Campbell CR23X data logger recorded the standard meteorological parameters in 1 min averages.

In the subsequent *W05US* field study, the mission objectives were expanded to include a focus on stable urban atmospheric conditions and turbulent airflow parameters. The original design of four 10-m meteorological towers and a 5-m tower on the building's roof remained the same. This consistency helped improve the interpretation of results when conducting thermodynamic comparisons between studies. Supplementing the design were three tripods strategically placed to quantitatively capture two additional airflow features: the leeside building reattachment zone and the two leeside horizontal side-eddies (indicated by the arrows pointing to the X locations in figure 3). One-minute mean data values were acquired by the Campbell CR23X data loggers mounted on each tower. The turbulent airflow parameterization required RM Young ultrasonic anemometers (Model 81000) to be added to the 10-m towers at heights of 10 m, 5 m, and 2.5 m above ground level (AGL). The thermodynamic data were sampled from the eastern side of the tower (to optimize sunrise effects), which allowed the ultrasonics to be mounted on the tower's climatologically windward side (west). Solar sensors were positioned on the south side of the tower. The Roof tower acquired sonic data at 5 m AGL and the three independent tripods sampled sonic data at 2 m AGL.

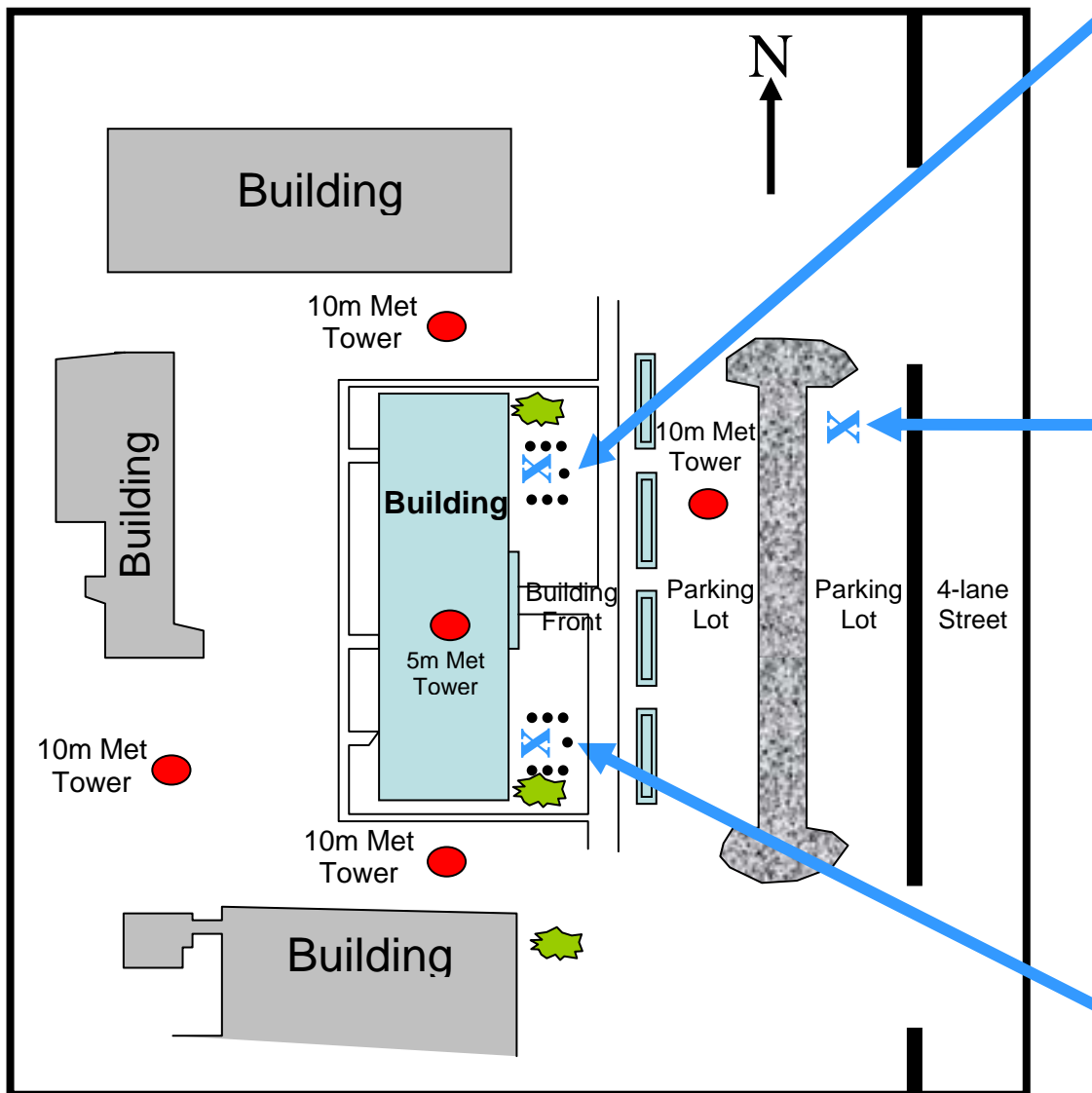


Figure 3. *W05US* test site plan view.

#### 4. Data Analysis and Results

The initial *W03US* data analysis reported that all three stability conditions (unstable, neutral, stable) were sampled around the subject building. The diurnal stability cycles observed included both the rural (night-stable, day-unstable, two transitions-neutral) and urban-city (24 h of unstable) patterns. In a subsequent analysis of the *W05US* data set, the stability characterization effort was refocused from the establishment of diurnal stability cycles to the characterization of

just the stable environment occurrences. The intent of this latter characterization was to understand the idiosyncrasies of the less frequent stable pattern first then return to the ill-defined diurnal urban cycle armed with enough information (pattern recognition) to extract a much more coherent picture of the two originally dichotomous conditions (rural and city cycles).

The stable characterization examined the data in terms of spatial and temporal patterns. The patterns were first measured in terms of “minutes of occurrences.” Then, to help describe the statistical distribution of extended stable periods, consecutive minutes of occurrence were grouped together into “cases.” The resultant statistics became the baseline for comparison in the current research and are presented in section 4.1.

NOTE: A “stable case” is defined as when the vertical (10 m minus 2 m) temperature differential is greater than 1 °C for 1 or more minutes.

#### **4.1 WSMR 2005 Urban Study Data Analysis and Results**

In the *W05US*, there were approximately 19 days of data acquired. From these days, approximately 50% of the days sampled reported stable conditions from each side of the building. The total stable minutes observed was greatest in the East tower (663 min). The North tower reported about half as many minutes in a stable status. The South and West towers (150 min) reported the least frequent occurrences. The average stable minutes per day ranged from about 8–35 min, but these numbers only showed a partial picture. One needed to consider the standard deviation to see that there was significant clustering in portions of the stability timeline. Figure 4 gives a much clearer picture of this timeline clustering. Converting the consecutive minutes of stable conditions into units of a “case,” the average case duration statistically ranged from 4–10 min. However, the longest stable case duration was 54 min and was found in the East tower. Table 1 provides a statistical summary of *W05US* stable conditions.

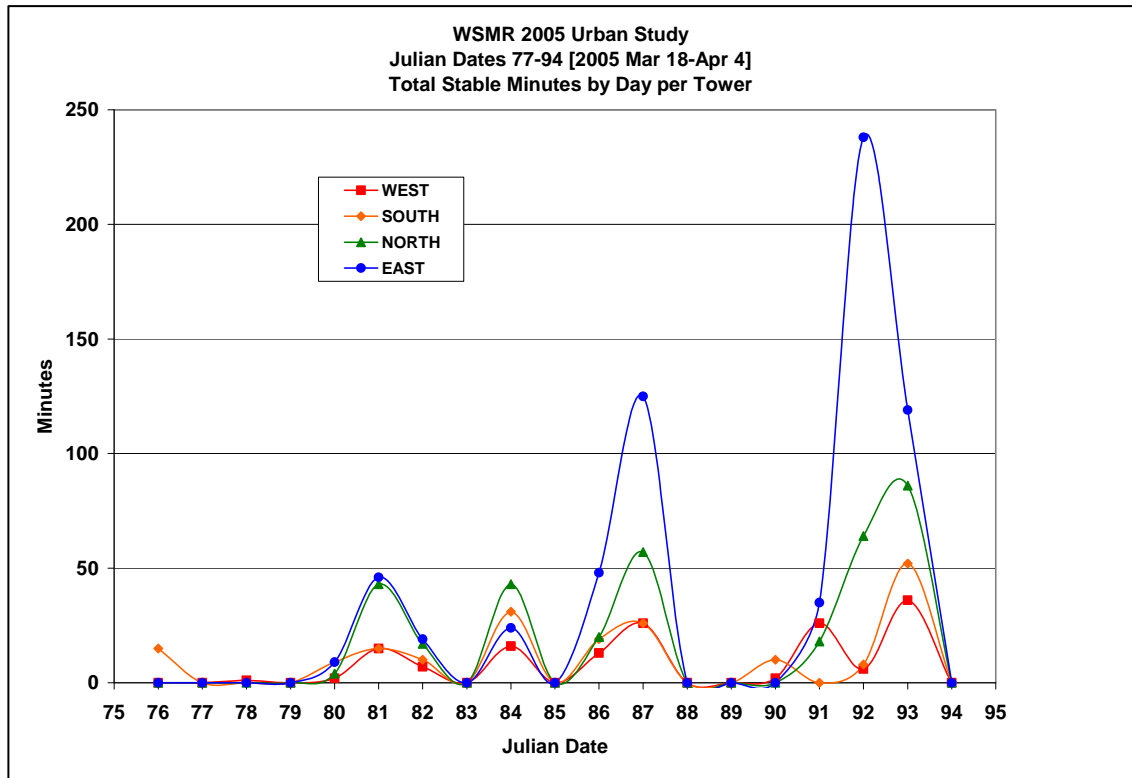


Figure 4. *W05US* time series of total stable minutes per day.

Table 1. Statistical summary of *W05US* stable conditions.

<b><i>W05US</i> Stable Conditions</b>	<b>West</b>	<b>South</b>	<b>North</b>	<b>East</b>
Julian day number sampled	76–94	76–94	76–94	76–94
Percent of days sampled in which stable conditions were reported (number of days)	58% (11)	53% (10)	47% (9)	47% (9)
Total minutes in stable conditions	150	195	352	663
Average stable minutes per day	7.9 [ $\pm 11$ ]	10[ $\pm 14$ ]	18[ $\pm 27$ ]	35[ $\pm 62$ ]
Maximum number of stable minutes per day	36	52	86	238
Number of cases	41	44	58	83
Average case duration (min)	3.7 [ $\pm 3.5$ ]	4.4 [ $\pm 3.4$ ]	6.1 [ $\pm 3.9$ ]	8.0 [ $\pm 10.7$ ]
Longest case duration (min)	20	16	17	54

NOTE: A “case” is defined as when the vertical temperature differential is greater than 1 °C for 1 or more minutes.

Using a 24-h timescale, the most populated time for a stable vertical profile was between 2100 and 0259 Local Time (LT). The second most populated time period was between 0300–0859 LT, followed by 1500–2059 LT. As expected, no stable samples were observed between 0900–1459 LT. Subtle to these numerical observations was the presence of a mini-heat island effect surrounding the building.

In summary, when the *W05US* stable environment occurred, there was a consistent preference for the east side first, followed by the north side. The south side and west sides appeared to be equivalently least favorable for reporting stable environments. The pattern of stable conditions seemed to occur in clusters, both in the time and spatial dimensions. The most populated time period for the stable conditions was between 2100–0259 LT.

#### **4.2 WSMR 2003 Urban Study Data Analysis and Results**

The initial stability analysis of the *W03US* data searched for general diurnal cycles to contrast with the rural environment. As explained earlier, what was found displayed both the rural and urban-city stability patterns. These results prompted the previously discussed *W05US* analysis specifically focusing on the stable environments (see section 4.1). With the *W05US* results completed, the question of whether the *W05US* findings were normal or an anomaly was raised. To help answer that question, the *W03US* data were reanalyzed with a focus on just the stable atmospheric patterns. What follows are the results:

- The total days sampled per tower varied between 7 and 9 days. On average, the towers' data reported stable conditions occurring in 65% of the days sampled. The tower reporting the greatest number of minutes in a stable environment was to the east. The second greatest number of stable condition minutes was from the South tower. The least amount of stable minutes was reported by the North tower. NOTE: The North tower also sampled the fewest days (7).
- The average stable minutes per day ranged from 12–40 min/day, with large standard deviations. Coupling these statistics with a timeline perspective (see figure 5), one can see a grouping of stable environmental conditions. The maximum number of minutes in a single day paralleled the overall total minutes in stable conditions: the East tower reported a maximum period of 236 min in a single day, followed by the South tower (151 min), the West tower (75 min), and the North tower (47 min).

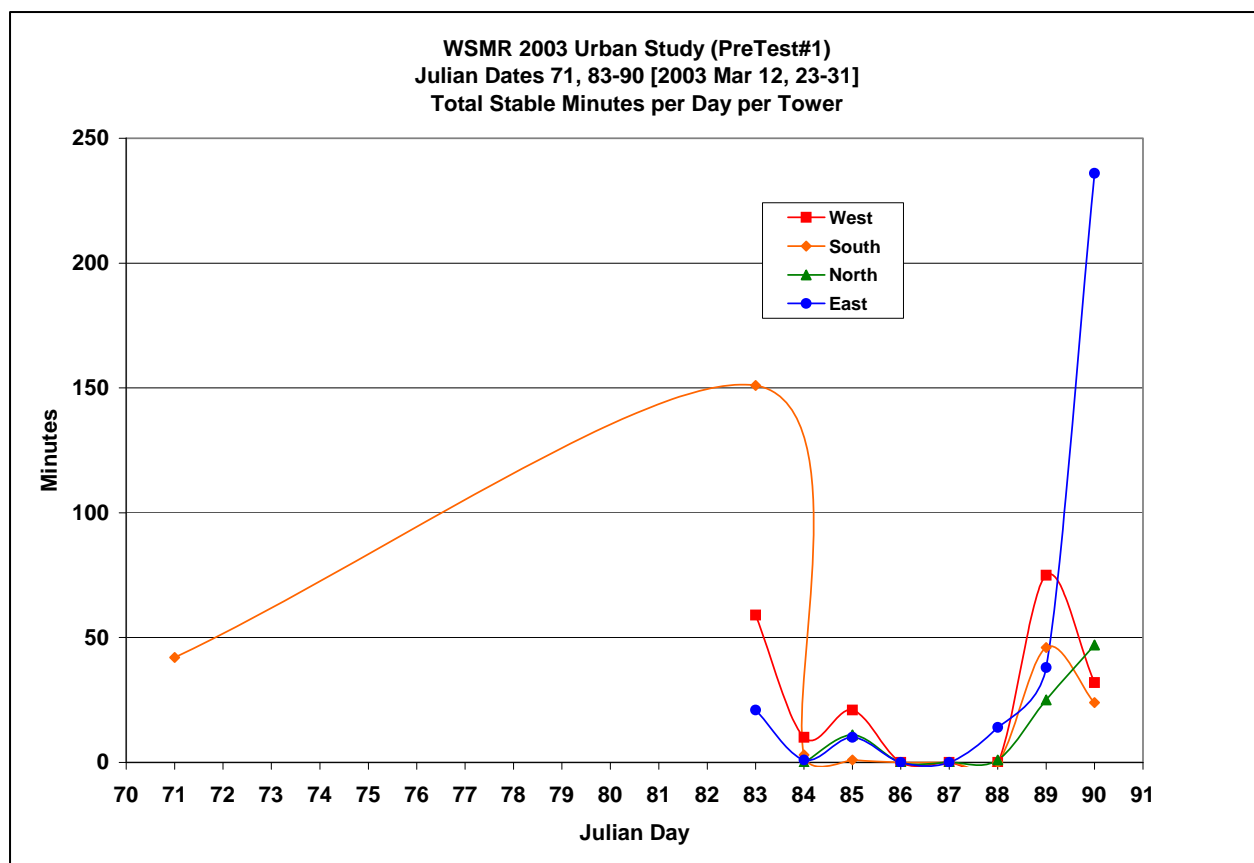


Figure 5. *W03US* time series of total stable minutes per day.

Grouping consecutive minutes together into “cases,” the longest duration for a case was 60 min and occurred in the East tower. The South and West towers each showed 37 min for their longest case. The North tower reported the longest case to be 14 min. On average, a case was between 5–11 min in length ( $\pm 4$ –14 min). Table 2 summarizes the stable atmosphere statistics from the *W03US* data set.

Table 2. Statistical summary of *W03US* stable conditions.

<i>W03US</i> Stable Conditions	West	South	North	East
Julian day number sampled	83–90	71, 83–90	84–90	83–90
Percent of days sampled in which stable conditions were reported	62%	67%	57%	75%
Total minutes in stable conditions	197	267	84	320
Average stable minutes per day	25 ( $\pm 29$ )	30 ( $\pm 49$ )	12 ( $\pm 18$ )	40 ( $\pm 80$ )
Maximum number of stable minutes per day	75	151	47	236
Maximum number of cases per day	26	37	16	30
Average case duration (min)	7.6 ( $\pm 8.9$ )	7.2 ( $\pm 6.8$ )	5.3 ( $\pm 4.2$ )	10.7 ( $\pm 14.5$ )
Longest case duration (min)	37	37	14	60

The stable patterns over a 24-h clock showed the period of greatest occurrence was between 2100–0259 LT, followed by 0300–0859 LT. As expected, no stable conditions were reported from 0900–1459 LT. No stable conditions were reported between 1500–2059 LT.

## 5. Observations from Comparing *W03US* and *W05US* Results

To help capture the urban stable atmospheric patterns, the comparison is subdivided into spatial and temporal comparisons.

### 5.1 Spatial Comparison

The most noticeable feature of the two stable atmospheric analyses is that stable conditions had their greatest occurrence east of the subject building. To the east, there was an open air environment. That is, starting at the building and moving eastward, there was a tailored green grassy area, followed by an unused parking lot and an open road. In contrast, to the west, south, and north of the subject building, there were additional buildings creating a closed-in environment. The potential for radiative cooling was much greater to the east of the building than in any other direction. No doubt, this condition contributed significantly to the dominance of the eastside stable pattern.

A strong secondary preference for stable conditions in *W05US* was to the north. In stark contrast, the *W03US* data reported that the least number of stable minutes around the structure was north of the building. The secondary stable condition preference for *W03US* was to the south. In *W05US*, the South tower recorded not the least number of stable minutes, but the second least. Since both these secondary preferences are situated directly in a canyon-type

environment (between aligned buildings), one might presume that local forcing, such as airflow, was involved in generating the secondary preferences.

A pattern consistent between the two urban studies was the clustering of stable cases. This feature had both spatial and temporal attributes. In this section, the spatial attributes will be described. Reviewing the chronological timelines (see figures 4 and 5), one can see that when stable conditions occur, the trend is for all towers to report these conditions. The duration of the conditions will vary, as described above in an earlier section. However, no side of the building was excluded from the stable environment condition.

Examining the case durations from all building sides, the overall statistical average is about 7 min ( $\pm 7$  min). Adding spatial perspective onto this number, the longest case duration results distinguishes the East tower as supporting the most extensive duration in both data sets. The other towers provide no consistent ranking, except that their occurrences are significantly smaller in magnitude than in the East tower. This leads us to the temporal comparisons.

## 5.2 Temporal Comparisons

The 24-h day can be subdivided into 4 quadrants, each highlighting a dominant solar-driven, atmospheric boundary layer attribute. Table 3 explains the correlation of these patterns.

Table 3. Diurnal atmospheric boundary layer cycle defined by the solar driven attributes.

Time Period	Solar Cycle Period	Radiative Attribute	Rural Stability Status
0300–0859	Sunrise	Transition (cooling to heating)	Stable/Neutral/Unstable
0900–1459	Daytime	Solar heating	Unstable
1500–2059	Sunset	Transition (heating to cooling)	Unstable/Neutral/Stable
2100–0259	Night	Solar cooling	Stable

The three Solar Cycle Periods supporting a stable environment are the Sunrise, Sunset, and Night Periods. In both the *W05US* and *W03US* data sets, the time of greatest stable condition occurrence was during the Night Period. This result was complimentary to the rural pattern but was somewhat of a surprise when it greatly exceeded the early morning hours with the most minutes of occurrence. In a rural environment that has been cooling all night (clear skies), the strongest stable environment occurs in the early morning hours. If one were to theorize that the building structure and surrounding environment would need more time to radiatively cool overnight than an open rural environment, this might lead to the presumption that the early morning hours would hold the more favorable time period for stable conditions. Data from both urban studies showed that these early morning hours (Sunrise Period) consistently ranked second to the Night Period.

Upon reevaluating the test site environment, several possible explanations were formulated. First, the subject building was an office building with a heating system that vented to the outside

environment. Active office hours during both field studies fell within the Sunrise Period and therefore the building's heating cycle would have commenced during that period. This anthropologic heat source would, in turn, have impacted the surrounding ambient building conditions.

Second, the three buildings surrounding the subject building were also actively used office buildings. These too had heating systems that vented to the outside environment. The effects for this venting would have been the same as above.

Finally, three of the hours during the Sunrise Period were in darkness and three hours were in daylight (equinox). There were very few obstacles preventing a healthy, solar warming of the ground around the building. From an independent rural-desert study, stability transition data were taken within 5 mi of this urban test site. In this rural study, there were no trees over the test site. The duration of the stability transition from desert stable to unstable conditions was often very quick (on the order of minutes) (2–4). Therefore, it is fair to say that the potential for stable conditions during the rural Sunrise Period was about 4–5 potential hours. NOTE: In the rural study, local effects were known to extend the stable conditions past sunrise. Extrapolating the short transition pattern of the rural study onto the urban environment, and disallowing for the rural local effects, one might reason that the urban environment only had 3–4 potential hours for stable conditions over the Sunrise Period. Comparing the 3–4 potential stable hours of the Sunrise Period with the 6 potential stable hours of the Night Period, one can see why the Night Period would hold the greater potential for stable conditions.

NOTE: During the urban Night Period, neither the subject office building nor the surrounding buildings were in active use.

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## **6. Conclusions**

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The NM Urban-Small Complexes Test Site was sampled for stable conditions over two independent time intervals. These times were March 2003 and March 2005. Climatologically speaking, this period was during the NM “windy season.” March was also when the equinox occurred, thus minimizing diurnal heating/cooling effects over the test site. The urban test site consisted of a single subject building with an open area to the east and buildings similar to the subject building on the other three sides. A single tower on each side of the building held thermodynamic sensors from which the stable conditions were extracted and compared. The comparison was divided into three phases: characterizing the spatial and temporal attributes of the *W05US* stable atmospheric patterns; characterizing spatial and temporal attributes of the *W03US* stable atmospheric patterns; and finally comparing the *W05US* and *W03US* stable characterization patterns. The strongest spatial and temporal attributes observed from both data resources were the following:

- The open environment east of the building showed the greatest occurrence of stable conditions, while the secondary preference was unclear. The secondary preference was presumed to be a function of local forcing factors involving the airflow and anthropological patterns.
  - The diurnal cycle for stable environments showed a consistently strong preference for the Night Period first, followed by the Sunrise Transition. The *W05US* data set reported the Sunset Transition as a third preferred for stable conditions. The shorter data set from *W03US* did not concur with this third preferred observation, but was in solid agreement with the first two preferences.
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## 7. Recommendations

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The climatologically strong winds of the *W05US* and *W03US* southern NM data sets may be skewing the observed stability patterns. Therefore, this author suggests that a measurement series be conducted under less windy conditions. Clear skies are recommended, since this would further enable the effects of radiative cooling. With radiative cooling dominating over advection, the potential for a very different and informative urban stable pattern would be significantly increased.

A second related suggestion involves the influence of the diurnal solar cycles. The equinox time period was chosen for the data acquisition described in this report. As explained above, this was to minimize diurnal heating/cooling effects. The opposite extreme, the solar solstice, needs to be examined. In New Mexico, the winter solstice time period is associated with the passage of fronts and would therefore be subject to periods of synoptically driven wind conditions. The NM June solstice time period coincides with, climatologically speaking, a “low-to-no” wind cycle. Thus, the latter time period would favor radiative cooling (first suggestion) and potentially provide the greater contribution to the urban stability research/investigation. In support of this recommendation, a summer solstice field study *Test Plan* and *Test Site Design* is presented in appendix A.

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## References

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1. CNN Web page, *Pollution fears cloud Olympic gala*, 2007 Aug 8, 10:52 EDT.  
[http://www.cnn.com/2007/WORLD/asiapcf/08/08/olympics.beijing.reut/index.html?eref=rss\\_topstories](http://www.cnn.com/2007/WORLD/asiapcf/08/08/olympics.beijing.reut/index.html?eref=rss_topstories) (accessed August 8, 2007).
2. Vaucher, G.; Bustillos, M.; Gutierrez, A. *Surface Layer Stability Transition Research Minimum Time Delay from Sunrise: 2001 March Case Study*; ARL-TR-2798; U.S. Army Research Laboratory: White Sands Missile Range, NM, May 2003.
3. Vaucher, G.; Bustillos, M. *Surface Layer Stability Transition Research Maximum Time Delay from Sunrise: 2001 June Case Study*; ARL-TR-2823; U.S. Army Research Laboratory: White Sands Missile Range, NM, May 2003.
4. Vaucher, G.; Bustillos, M. *Surface Layer Stability Transition Research, Min. Neutral Event-to-Sunrise Time Interval: 2001 September Case Study*; ARL-TR-2827; U.S. Army Research Laboratory: White Sands Missile Range, NM, May 2003.

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## **Appendix A. Test Plan and Test Site Design for a NM Summer Solstice Urban Field Study**

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The following is an executable Test Plan for a summer solstice *WSMR Urban Study* field study. The mission objectives include both stability and airflow, since these parameters are ultimately very much interrelated. The Test Plan commences with the foundational administrative requirements of the field study and concludes with the *Preliminary Results Summary*. The Plan presumes all funding is resident. A list of the hardware and data acquisition requirements is tabulated for quick reference. A sketched “Top-Down View of the Building Test Site” (figure A-1) is included with this field study document.

## WSMR URBAN STUDY: STABILITY AND AIRFLOW AROUND A SINGLE BUILDING

[2007 Aug, Vaucher]

### MISSION OBJECTIVES:

- (1) To characterize surface layer stability patterns in an urban environment.
- (2) To characterize behavior of turbulent airflow around and above a single building.

### LOCATION:

White Sands Missile Range, NM.

### EQUIPMENT:

Sensors/Variables:	Campbell Units	P, T, RH, Solar Radiation (Net and Gross), WS/WD.
	Sonics	u, v, w, T, c.

### TEST PLAN:

<b>200x</b>	Oct/Nov	Design field study	Draft Study (Test) plan. Identify hard/software requirements.
	Nov/Dec		Calibrate feasibility of test execution.
	Dec	Finalize Study Plan	Test Plan initialed by participants.
<b>200y</b>	Jan	Permissions	Initiate Safety, Security, Site permissions.
	Mar/Apr	Pre-Study Calibration	Wind sensors need the windy season for calibrations.
	May/June	Pre-Study Calibration	Thermodynamic sensors calibrate easier without winds.
	June	Tower/Tripod Setup	Install Towers/Tripods.
	<b>Jun 13-29</b>	<b>Field Test</b>	<b>Acquire data. Acquire synoptic meteorological data.</b>
	June/July	Data/Tower down	Remove sensors, Secure towers; setup Calibration tripods.
	July/Aug	Post-Study Calibration	Calibrate all sensors after the field study.
	July 10	IPR	Internal Progress Review (IPR) for WSMR Urban Study.
	Aug	Post-Study Teardown	Remove/secure all equipment from Post Study Calibration.
	Aug/Sept	Data Review	Initiate review of data analysis results.
	Sep	Summary	Prepare/submit <i>WSMR Urban Study Preliminary Summary</i>

### TOP DOWN VIEW OF THE BUILDING TEST SITE

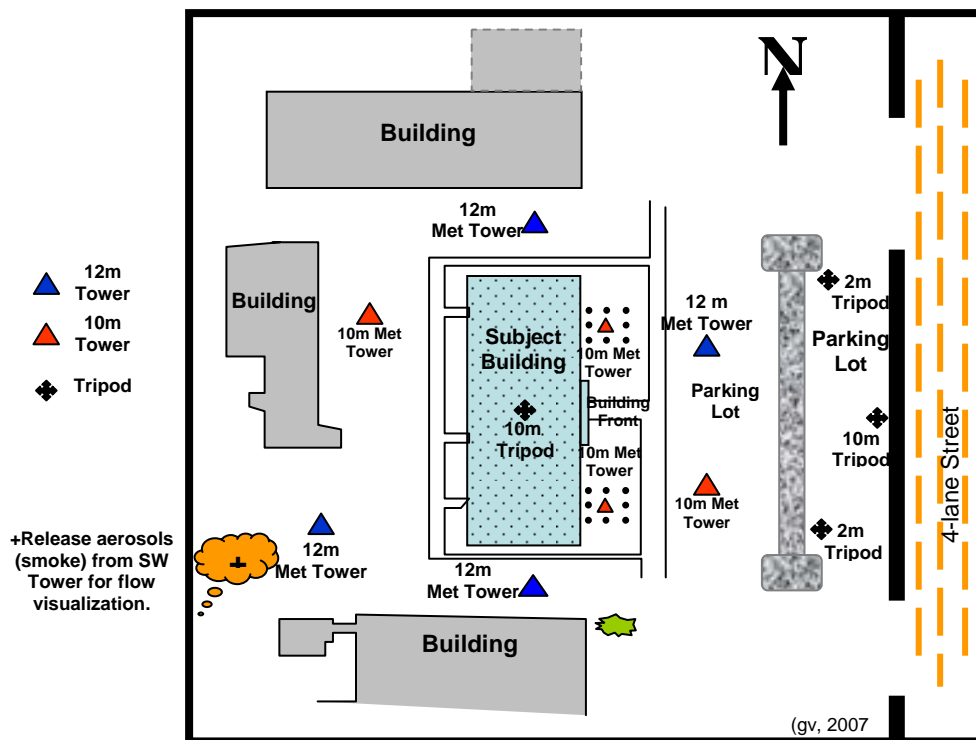


Figure A-1. Top-down view of a *Solstice-WSMR Urban Study* test site.

## **HARDWARE REQUIREMENTS**

(2007 Aug, Vaucher)

### **TOWER SUMMARY:**

<b>TOWER HT</b>	<b>QUANTITY</b>	<b>LOCATIONS</b>
12m	4	SW, S, NE, N
10m	4	SE, NE and SE side eddies, WCanyon.
10m Tripod	2	Roof and Reattachment-east
2m Tripod	2	Reattachments-north and south

### **SENSOR SUMMARY:**

<b>SENSOR</b>	<b>QUANTITY</b>	<b>LOCATIONS</b>
Sonics	32 (29)	All Towers/Tripods, all levels
Barometers	5	SW, NE, S, N, Roof
Thermometers	5	SW, NE, S, N, Roof (10m)
T/RH	5	SW, NE, S, N, Roof (2.5m)
Wind Monitors	5	SW, NE, S, N, Roof (5m)
Pyranometers	5	SW, NE, S, N, Roof (2.5m)
Net Radiometer	5	SW, NE, S, N, Roof (2.5m)
Data Loggers	5 Campbells	SW, NE, S, N, Roof
White boxes	12	All Towers/Tripods
Power cables	12	All Towers/Tripods (extension cords)
Laptops	12	All Towers/Tripods

### **SENSOR LAYOUT:**

<b>LOCATION</b>	<b>TWR HT</b>	<b>2.5m Level</b>	<b>5m Level</b>	<b>10m Level</b>
<b>SW</b>	12m	Sonic*, P, T/RH, Net/Gross Rad	Sonic, WS/WD	Sonic, T
<b>NE</b>	12m	Sonic, P, T/RH, Net/Gross Rad	Sonic, WS/WD	Sonic, T
<b>S</b>	12m	Sonic, P, T/RH, Net/Gross Rad	Sonic, WS/WD	Sonic, T
<b>N</b>	12m	Sonic, P, T/RH, Net Gross Rad	Sonic, WS/WD	Sonic, T
<b>Roof</b>	10m Tripod	Sonic, P, T/RH, Net/Gross Rad	Sonic, WS/WD	T
<b>West Canyon</b>	10m	Sonic	Sonic	Sonic
<b>NE Eddy</b>	10m	Sonic	Sonic	
<b>SE Eddy</b>	10m	Sonic	Sonic	
<b>SE</b>	10m	Sonic	Sonic	Sonic
<b>Reattachment-Ctr</b>	10m Tripod	Sonic	Sonic	Sonic
<b>Reattachment-North</b>	2m Tripod	Sonic		
<b>Reattachment-South</b>	2m Tripod	Sonic		

\*“Sonic” reference means the acquisition of the standard sonic variables at 20Hz: u, v, w, WS/WD, c, T. The other short-hand means the following: P (Pressure), T/RH (temperature/relative humidity), Net/Gross Rad (net and gross solar radiation), and WS/WD (wind speed/wind direction). These latter parameters should be acquired at less than or equal to 1min averages.

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## Appendix B. WSMR 2003 Urban Study – Stable Characterization

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Appendix B provides the key *W03US* graphical summaries used in the stable atmospheric characterization intercomparison.

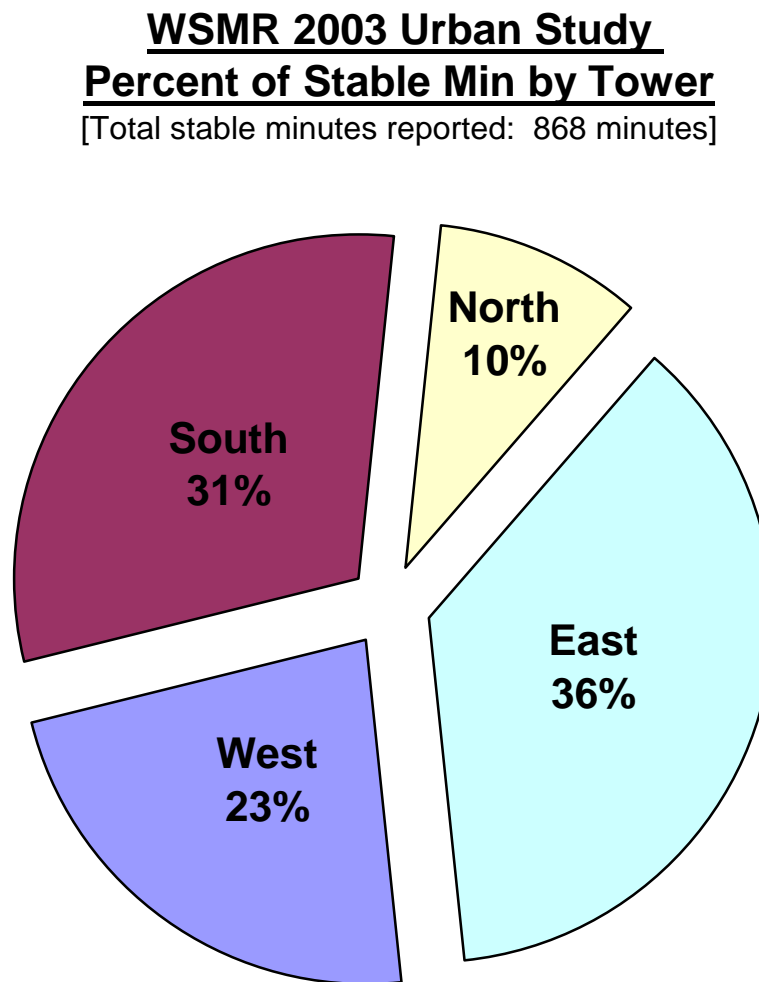


Figure B-1. Percent of stable minutes by tower for the *W03US*.

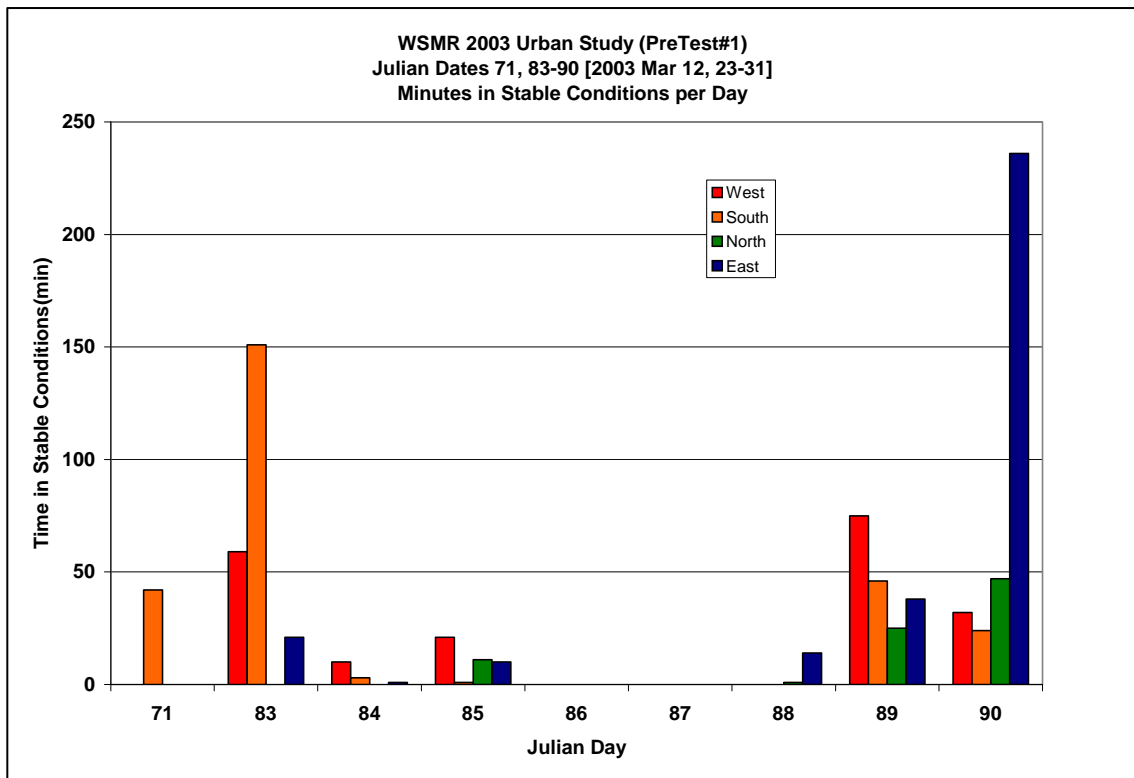


Figure B-2. Minutes in stable condition per day for the *W03US*.

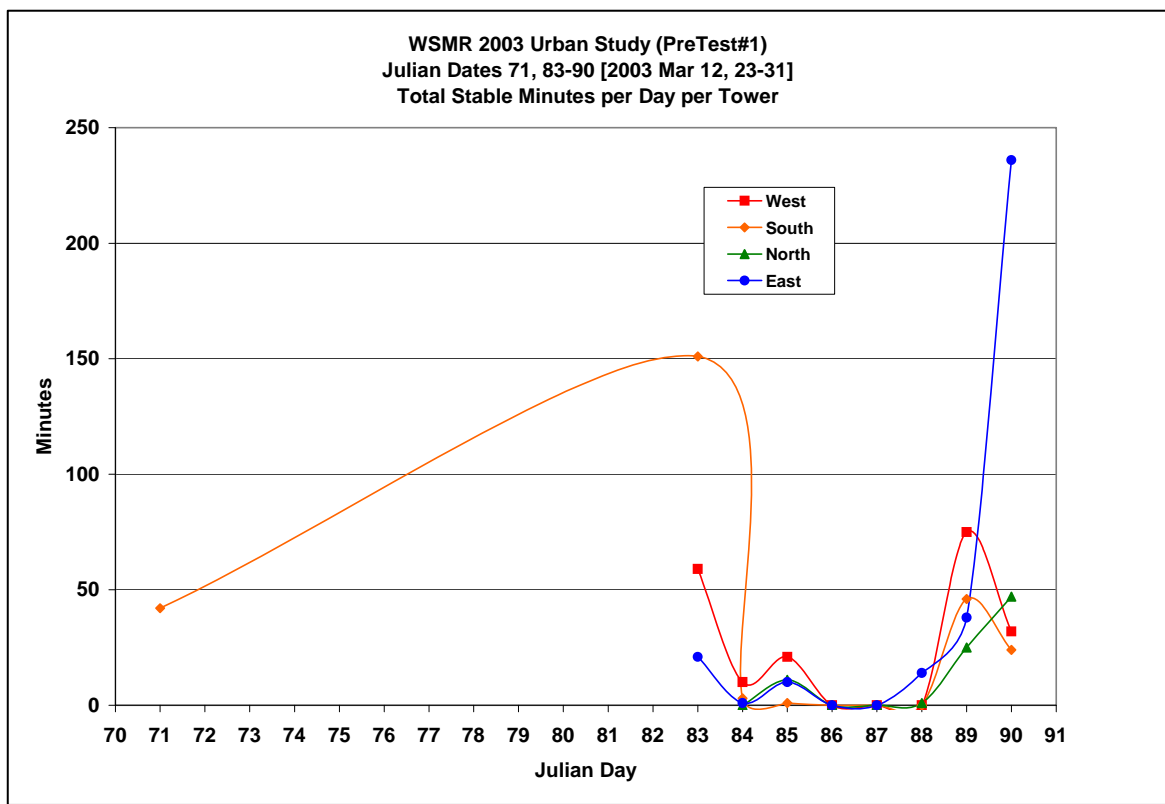


Figure B-3. Total stable minutes per day per tower for the *W03US*.

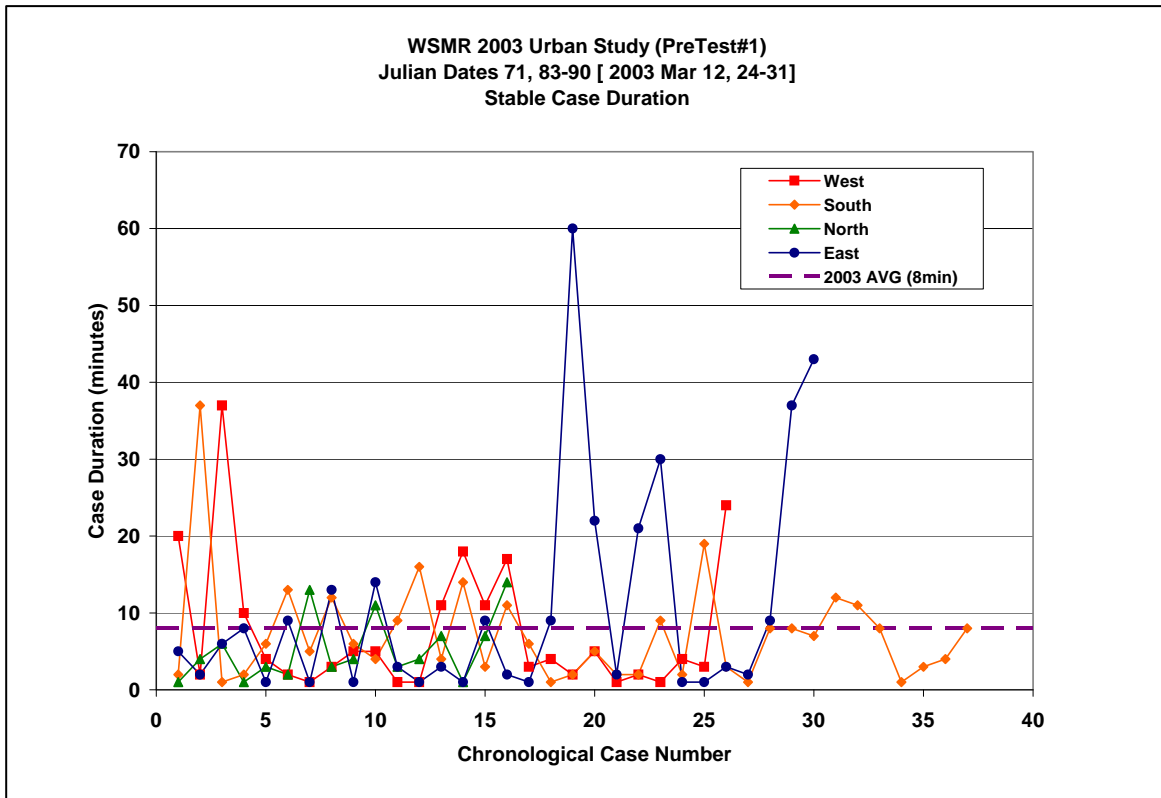


Figure B-4. Stable case duration for the *W03US*.

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## Appendix C. WSMR 2005 Urban Study – Stable Characterization

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Appendix C provides the key *W05US* graphical summaries used in the stable atmospheric characterization inter-comparison.

**WSMR 2005 Urban Study**  
**Percent of Stable Minutes by Tower**  
[Total Stable Minutes Reported: 1360 minutes ]

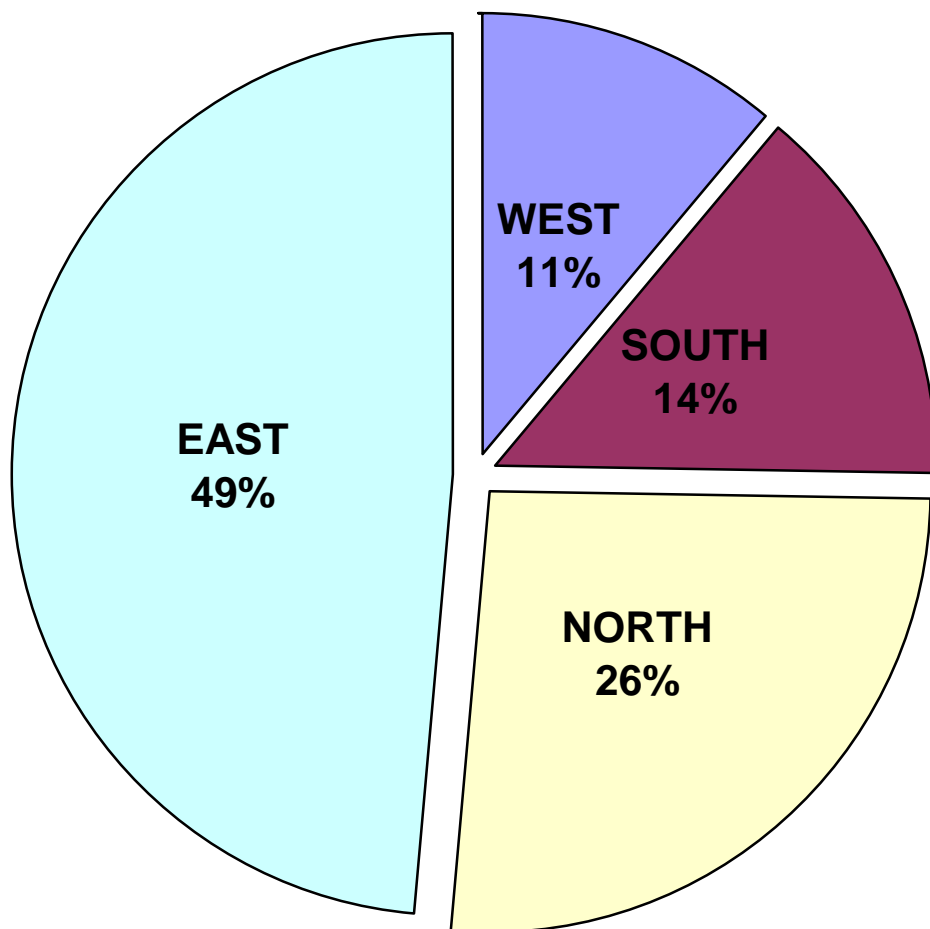


Figure C-1. Percent of stable minutes by tower for the *W05US*.

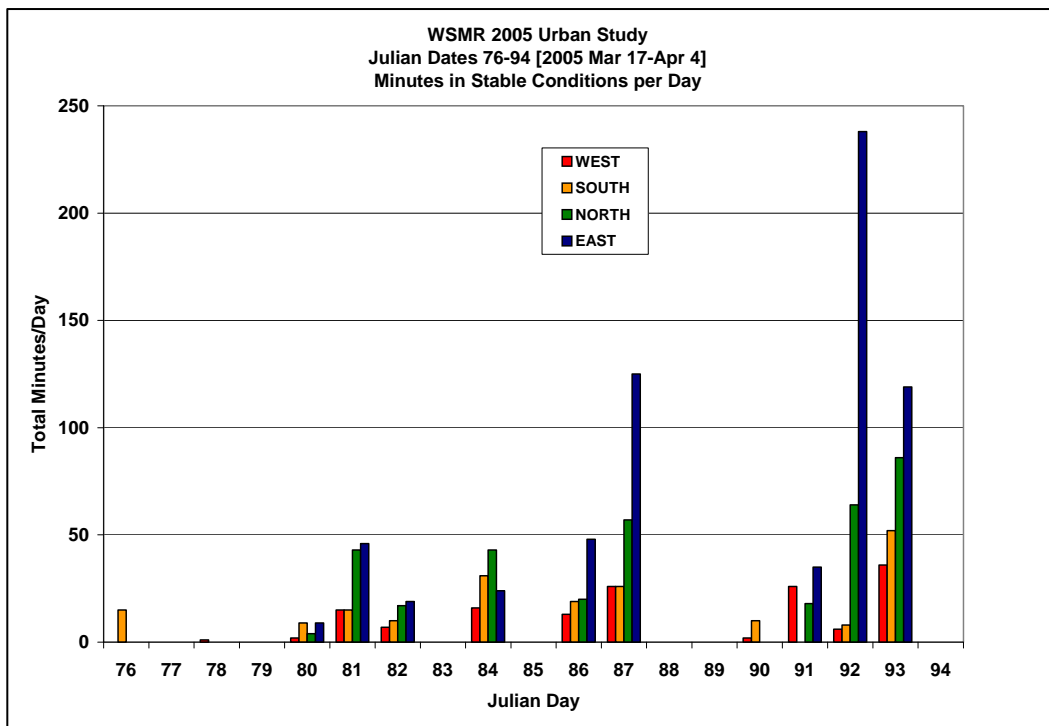


Figure C-2. Minutes in stable condition per day for *the W05US*.

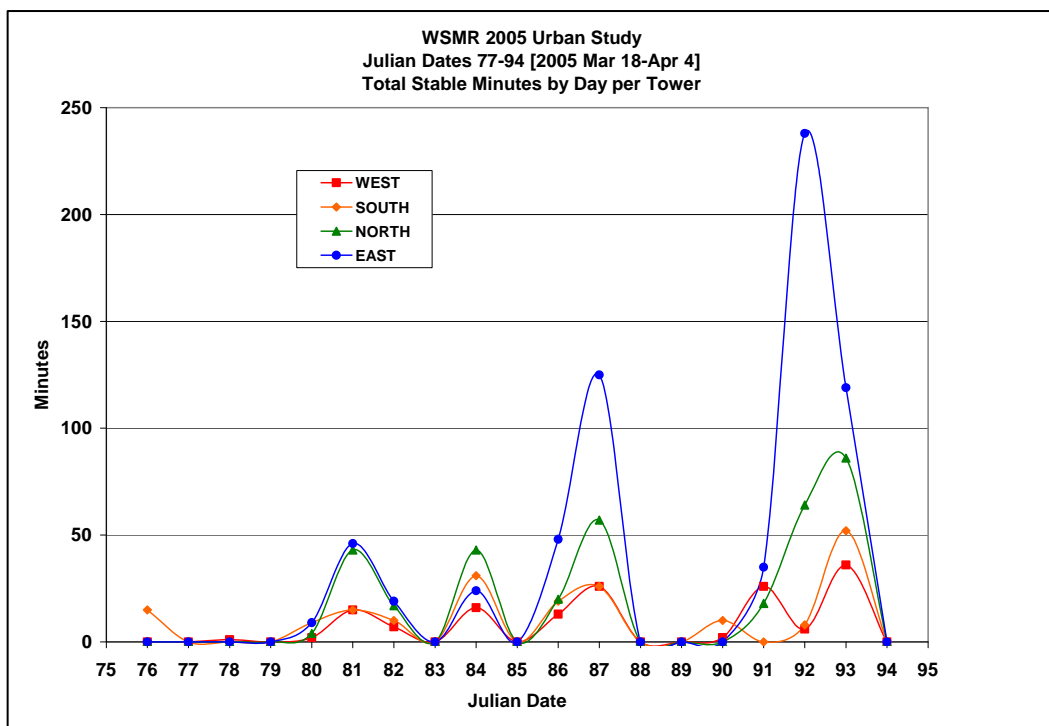


Figure C-3. Total stable minutes per day per tower for *the W05US*.

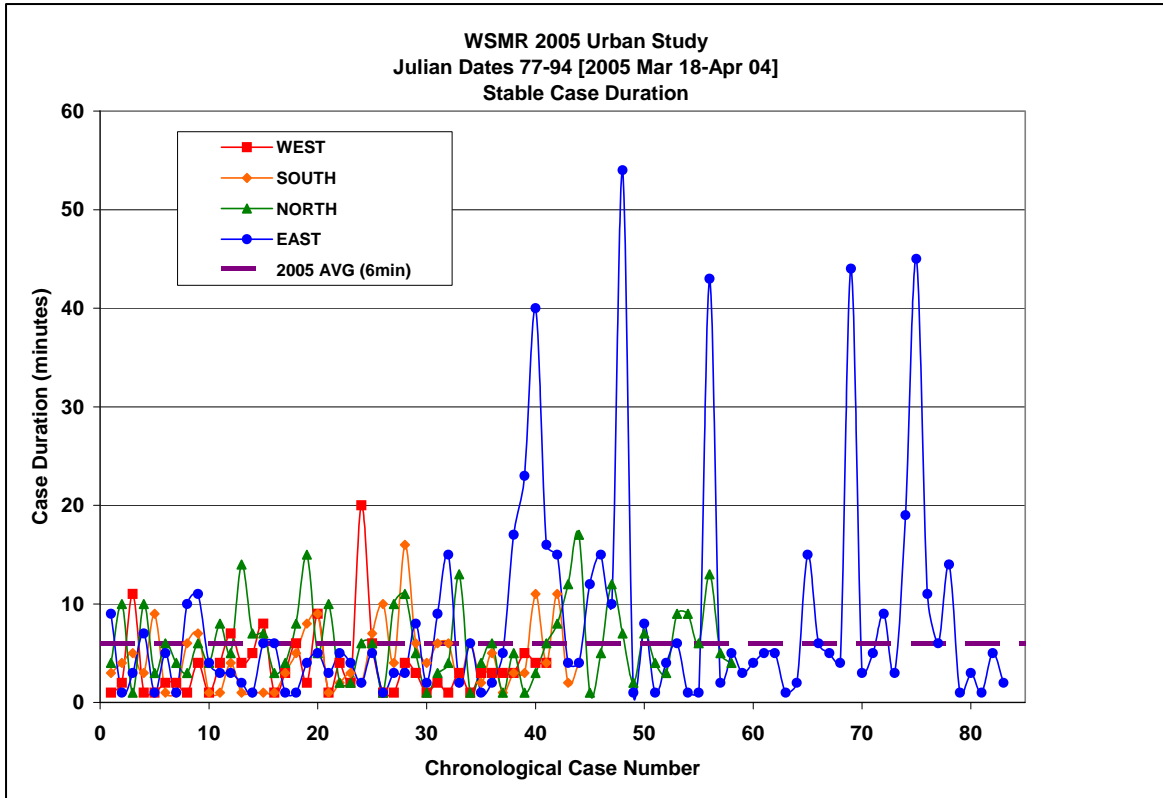


Figure C-4. Stable case duration for the *W05US*.

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## Acronyms

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ABL	atmospheric boundary layer
AGL	above ground level
IPR	Internal Progress Review
LT	Local Time (Mountain Time)
Net/Gross Rad	net and gross solar radiation
P	pressure
T/RH	temperature/relative humidity
<i>W03US</i>	<i>WSMR 2003 Urban Study</i>
<i>W05US</i>	<i>WSMR 2005 Urban Study</i>
WS/WD	wind speed/wind direction
WSMR	White Sands Missile Range

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